DELAY STABILITY OF THE TWSTFT EARTH STATION AT VSL

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Abstract

Frequency and time transfer methods rely on the stability of the propagation time of the signals through the systems involved. For TWSTFT the stability of the delays encountered in the earth station by the transmission of the local 1 PPS signal, as well as that of the received remote 1 PPS signal, determines the uncertainty at sub-nanosecond level for such transfers. The characteristics of the TWSTFT earth station at NMi Van Swinden Laboratorium (VSL) based on data accumulated with its automated delay measurement system during about one year are presented and discussed in more detail. Delay stabilities TDEV of 100 ps for tau = 1 h to 50 d are obtained, and frequency stabilities ADEV of 2.2 E-15 for tau = 1 d.

INTRODUCTION

For the measurement of the difference of the delay in the transmit part (TX) and the delay in the receive part (RX) of the TWSTFT earth station at VSL, an automatic calibration system [3] has been developed, based on the use of a specially-at-VSL-developed satellite simulator SATSIM method [1,2]. The knowledge of this TX - RX delay is necessary if clocks at two remote sites are to be compared using the TWSTFT method; if both stations are equipped with such a system no additional visits [4] of other calibration equipment is necessary for absolute time comparisons. This paper shows what long-term performance can be expected from this TX-RX calibration. This method uses a calibrated reference cable, and this essential cable is also calibrated automatically in the automatic system. The main parts of the system used for the calibration are part of the TWSTFT equipment; only coaxial transfer switches are added, 70 MHz and 1425 MHz sine wave sources and the SATSIM, as shown in Fig. 1a.

The cables and their delays are defined as follows (Fig. 1a + b):
A is the cable from the Mitrex modem 70 MHz TX output to the up-converter Fup;
B is the cable from the down-converter Fdn to the 70 MHz RX input of the Mitrex modem;
C is the cable from the 70 MHz CW generator to the output of the amplifier;
HL is the cable from amplifier output to the Sat. Simulator input;
HL' is a cable equal to cable HL, and runs from the difference frequency generator DF to the other input of the Sat. Simulator; cable L is the sum of HL and HL';
CL is the Reference cable being calibrated each time; it is the sum of C and HL;

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RX is the Receive delay: the sum of the delay from the Sat. Simulator to the Feed, the delay from Feed to the output of the down-converter Fdn and cable B;
TX is the Transmit delay: the sum of the delay of cable A, from the input of the up-converter Fup to the Feed, from the Feed to the Sat. Simulator;
TX-RX is the value of interest for TWSTFT.

STABILITY OF THE REFERENCE CABLE DELAY CALIBRATION

Firstly, the delay of the reference cable CL is determined. Using a three-corner-hat method, the delay of C is determined from half of the sums of the delays of cables C+B and C+A minus the sum of cables A and B.
The stabilities of these three sums do not differ much; the structure of the variations (Fig. 2a and Fig. 3a) that can be seen, are originating in the MITREX modem itself, not in the cables. Also, a small slope during the year can be seen. Fig. 2a and 2b show the stability of A+B and 3a and 3b that of cable C+B. TDEV varies from 24 ps for tau = 1 h to maximum 150 ps for tau = 1 week. At MJD 50612 the original cable C has been replaced by a new cable with 70 ns less delay. The data taken after the replacement,which included the delay of cable C, have been corrected for this.

The delay of HL is determined by measuring C+B+L (Fig. 4a + b) and subtracting C+B and dividing the result by two. HL alone is determined with a very good long-term stability as shown in Fig.5a and 5b, a TDEV of 10 ps at tau = 1 h to 23 ps for tau = 50 days! At MJD 50612 a residual step of 100 ps due to the replacement for cable C is visible and causes the rise of TDEV at tau of 20 d and 50 d.
Now the wanted delay of the reference cable CL is the sum of C and HL and its stability is shown to be 20 ps at tau = 1 h to a maximum of 72 ps at tau = 1 week in Fig. 6a and 6b.

STABILITY OF THE TOTAL TRANSMIT AND RECEIVE DELAY INCLUDING UP- AND DOWN CONVERTERS, HPA AND LNA

The next measurement is the sum of cables CL + RX which include the RF path from SATSIM to the receiver antenna and the down-converter and cable B. The total RX delay is calculated from CL+RX and subtraction of CL. Stability is shown in Figs. 7a+b, 8a+b; TDEV is constantly about 100 ps.
Then the sum of TX+RX is measured and the delay of TX (including the up-converter and RF path to the SATSIM) is calculated by subtraction of the RX delay determined before. Stability is shown in Figs. 9a+b, 10a+b, again a TDEV of about 100 ps for tau = 1 h to 50 d.

STABILITY OF THE TRANSMIT - RECEIVE DELAY DIFFERENCE

Finally the TX-RX delay is calculated by subtraction of the RX delay from the TX delay; see Fig.11a and 11b for the stability. Now TDEV varies from 250 ps at tau = 1 hr to 110 ps for tau = 50 d. The associated frequency stability is showing mainly flicker phase noise and a modified Allan deviation of 2.2 E-15 is obtained at tau = 1 day, 2.5 E-16 at 10 d and 4.5 E-17 at 50 d.

Fig 12a+b show the outside temperature and its stability. These figures help to see if correlations of delay stability with temperature exists. The 'TEMPDEV' shows a rise after 2 h and reaches a maximum as expected at a diurnal tau =12 h of 2.2 degrees C and drops to 1.2 at tau = 18 h and 24 h. For TX-RX we also find a drop of TDEV from 150 ps at tau = 12 h to 120 ps at tau = 18 h and 110 ps at tau = 24 h.

CONCLUSION

The TX-RX delay at the VSL earth station is **stable to a TDEV of about 100 ps for tau of up to at least 50 days** and the system is **stable in frequency to 2 E-15 for tau = 1 day** . But while these delay changes are measured in near real time, they can be subtracted from actual Two-Way data, and enable the clock comparisons to **an even much better level than the stability reported here.** This could be demonstrated when two good H-masers were compared using TWSTFT stations equipped with such an automated delay measuring system and the TWSTFT data be corrected for the measured delay changes. So far, a best TDEV of 0.22 ns for tau = 1 h to 0.18 ns for tau = 1 d from hourly sessions of 300 s during 32 days using an "Atlantis" modem on a baseline of 2400 km has been reported [10].

The VSL full TX-RX stability results are up to two times better than the results reported by the Technical University Graz (TUG) [5, 7, 11, 12] when taking into account that the half TX-RX delay stability was reported; maybe this difference is because at VSL the up- and down-converter are mounted inside the building, just under the roof , while at TUG they are outside at the antenna.

RECOMMENDATIONS

Unfortunately the improvement of the performance of TWSTFT using delay measurements cannot be demonstrated further with good clocks now: the two laboratories equipped now with automated delay measuring systems (TUG and VSL) have no H-masers available and the labs that do have H-masers do not (yet) have an automated delay measuring system. This dilemma should be solved in the near future!

Another finding is that the used MITREX modem is sensitive to environmental factors for tau of 3 h to 10 d even when it was kept in a room at a temperature of 23 degrees centigrade controlled to about 0.3 degrees C and a relative humidity of 45% controlled to about 5 % RH. Also, it was noticed that the non-linearity of delays measured by the MITREX modem when

changing the length of the cable in known increments under circumstances is 100 ps or more. Some mismatch and / or cross-talk in the modem might be the cause of this. So modems still should be improved.

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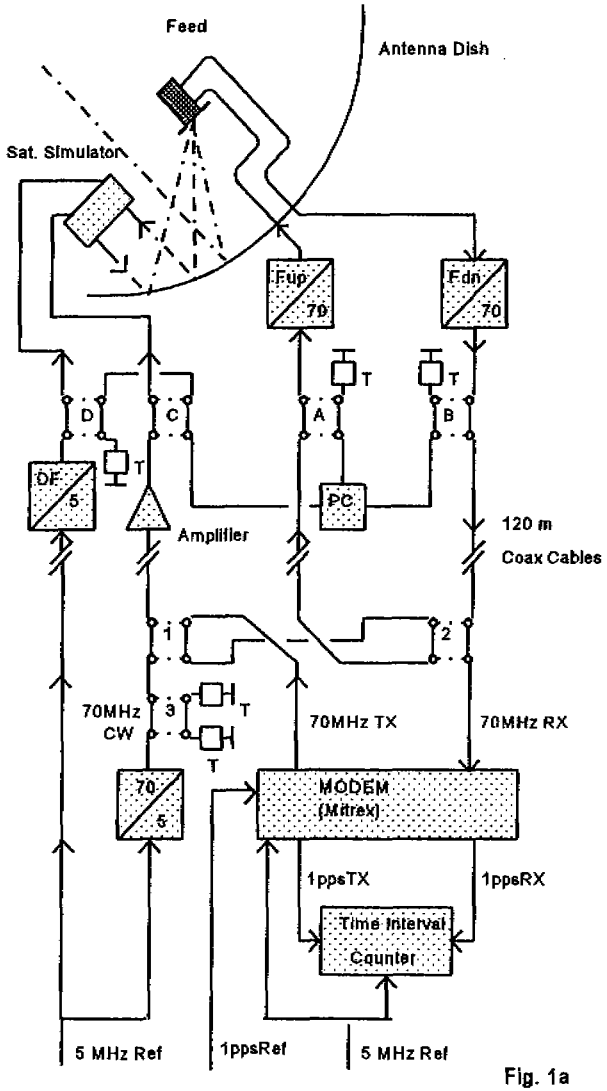

Feed
Antenna Dish
Sat. Simulator
Fup
70
Fdn
70
T
T
D
C
A
B
DF
5
T
PC
Amplifier
120 m
Coax Cables
1
2
70MHz
CW
3
T
T
70MHz TX
70MHz RX
70
5
MODEM
(Mitrex)
1ppsTX
1ppsRX
Time Interval
Counter
5 MHz Ref
1ppsRef
5 MHz Ref

Fig. 1a

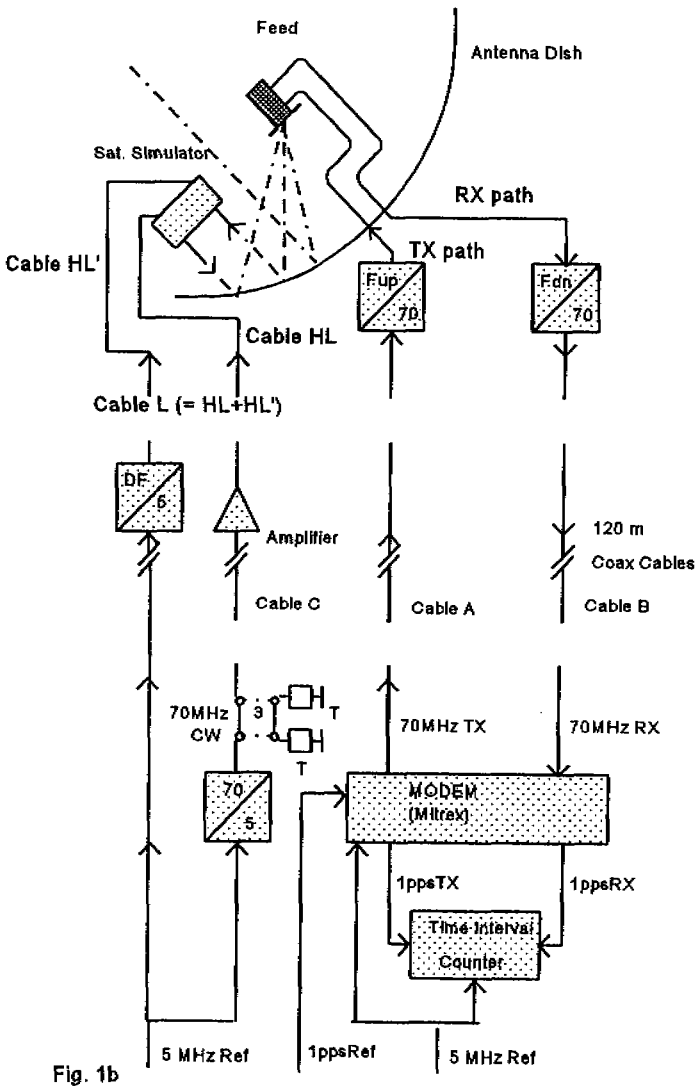
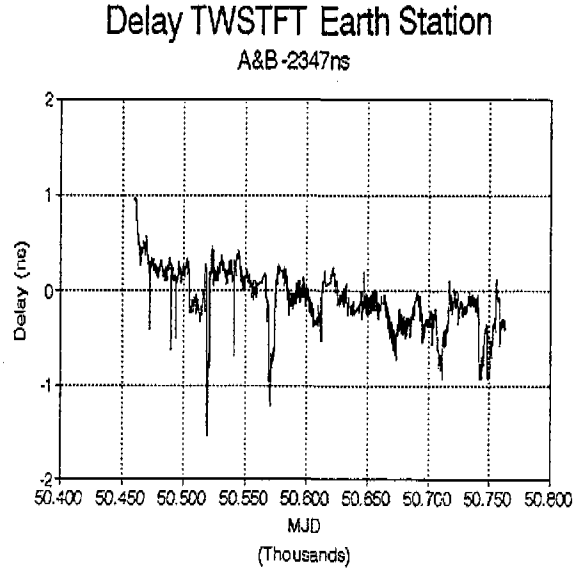

Feed
Antenna Dish
Sat. Simulator
RX path
TX path
Cable HL'
Fup
70
Fdn
70
Cable HL
Cable L (= HL+HL')
DF
5
Amplifier
120 m
Coax Cables
Cable C
Cable A
Cable B
70MHz
CW
3
T
T
70MHz TX
70MHz RX
70
5
MODEM
(Mitrex)
1ppsTX
1ppsRX
Time Interval
Counter
5 MHz Ref
1ppsRef
5 MHz Ref

Fig. 1b



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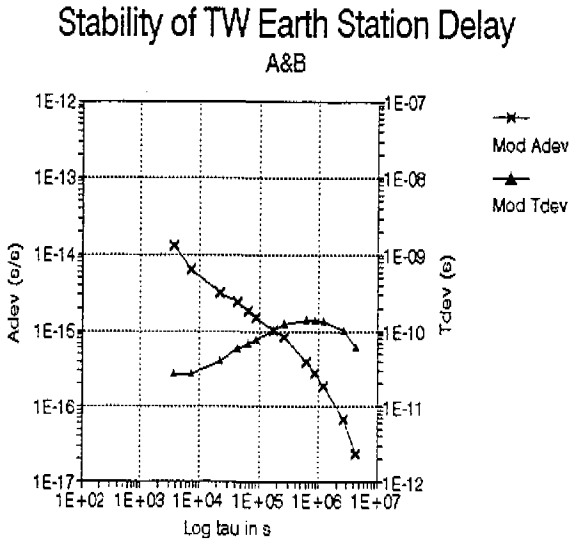
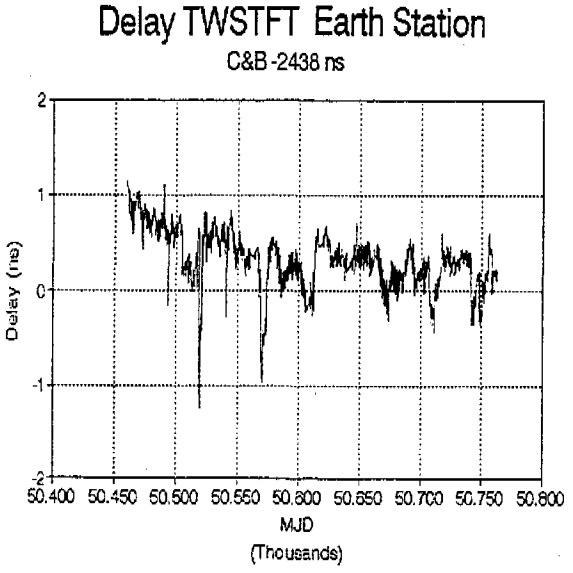


Fig. 2b



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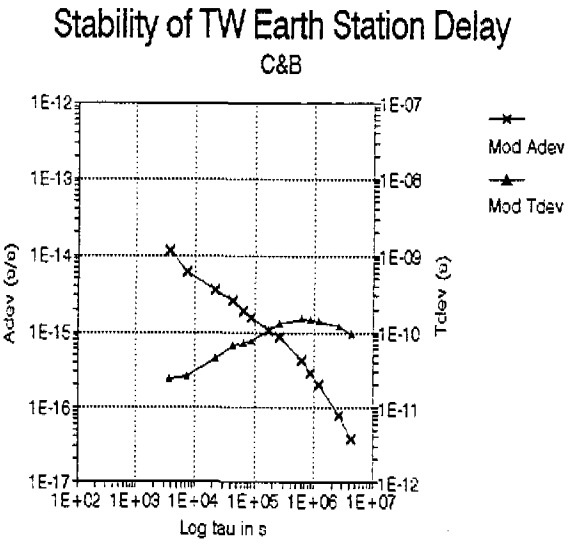

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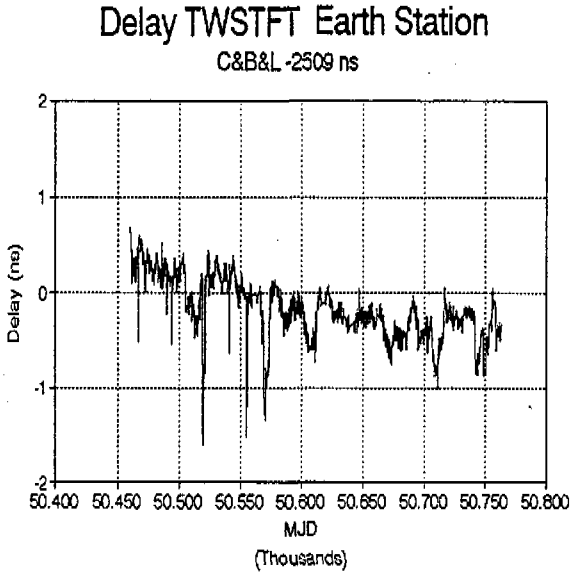

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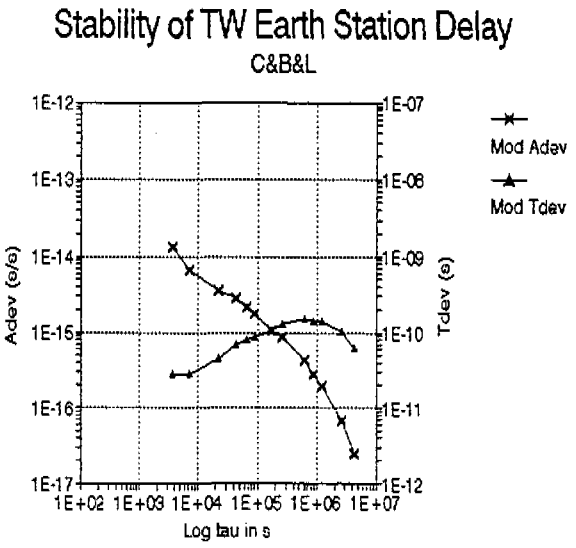

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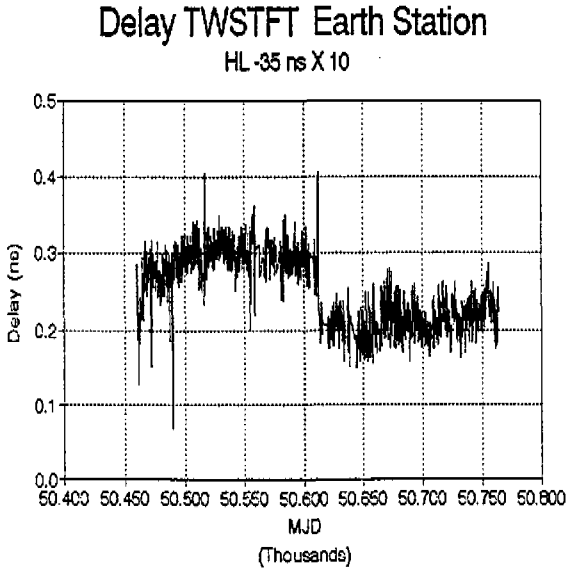

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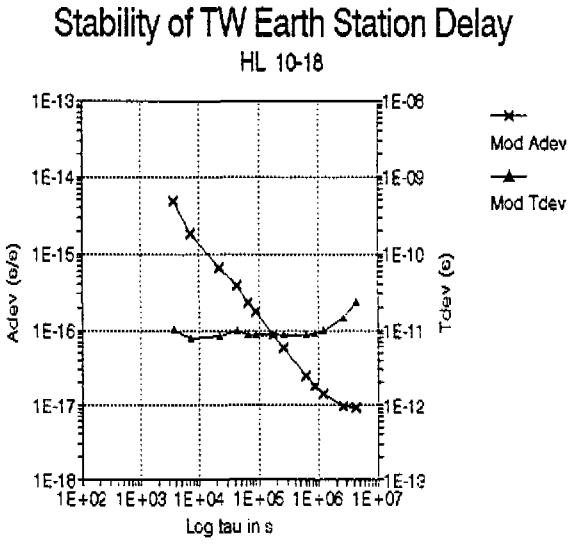

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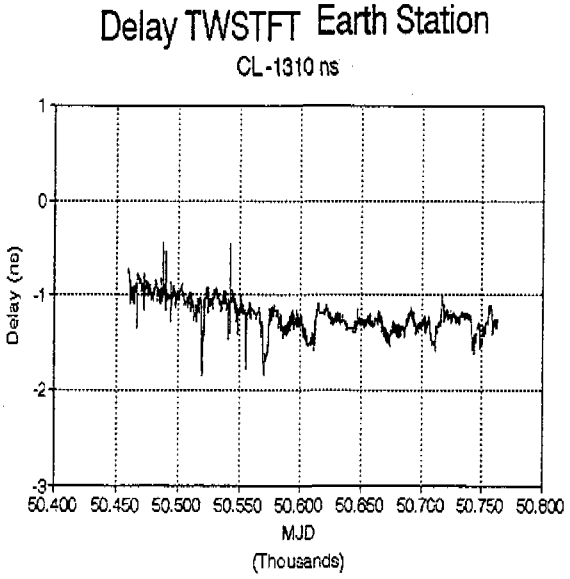

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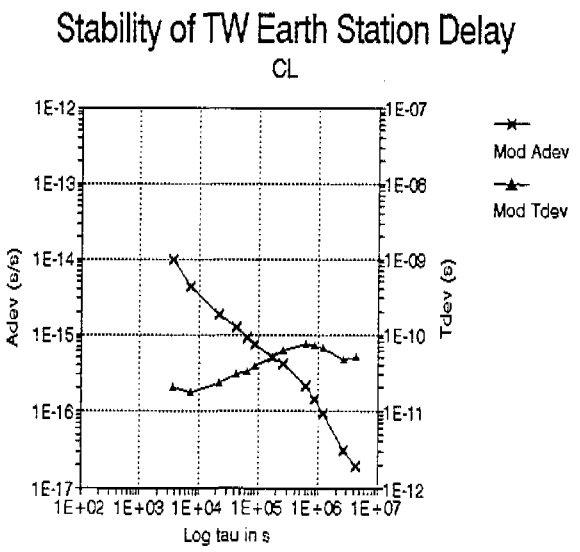

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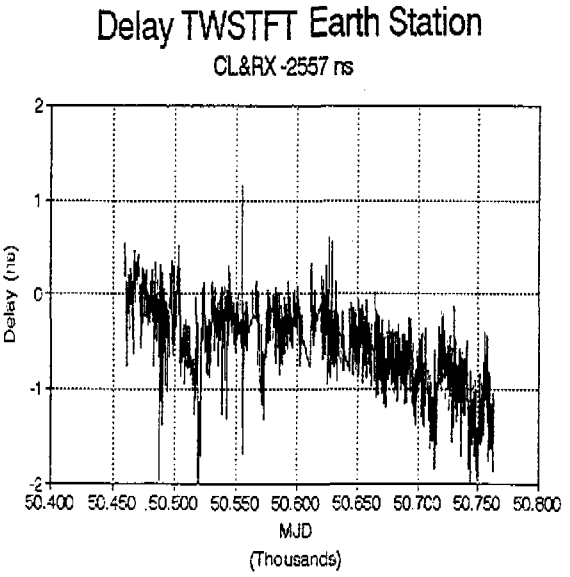

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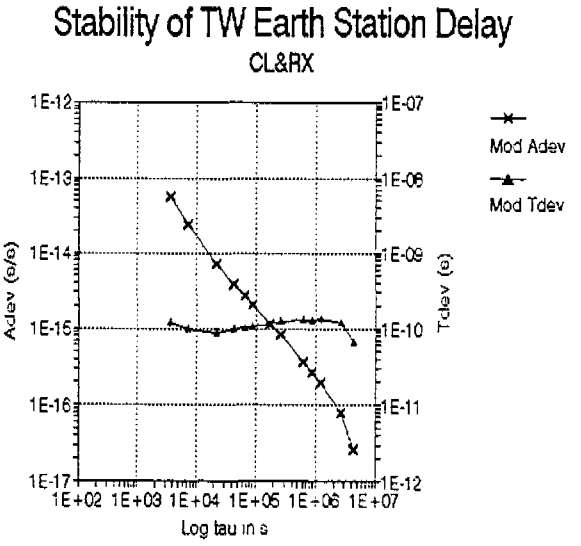

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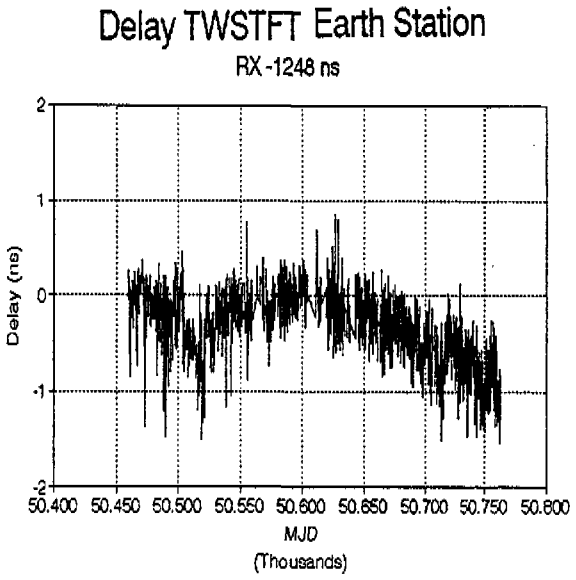

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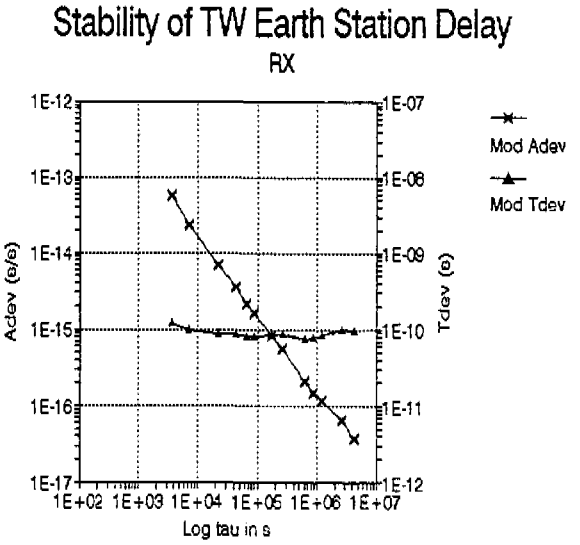

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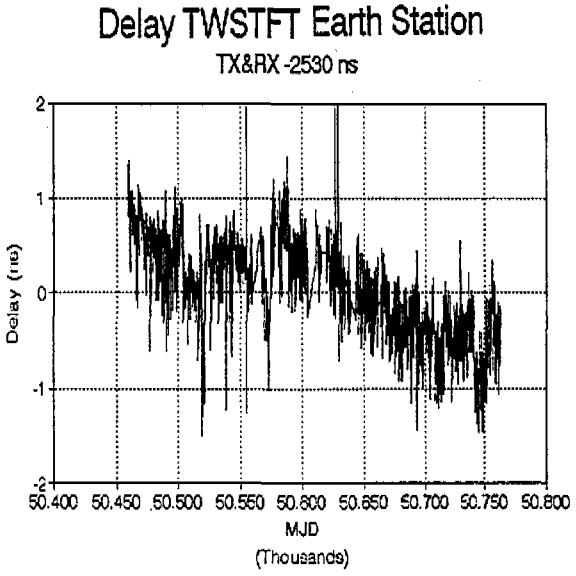

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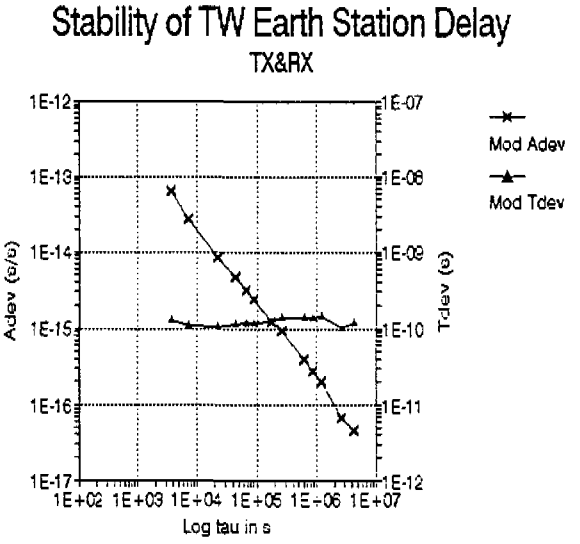

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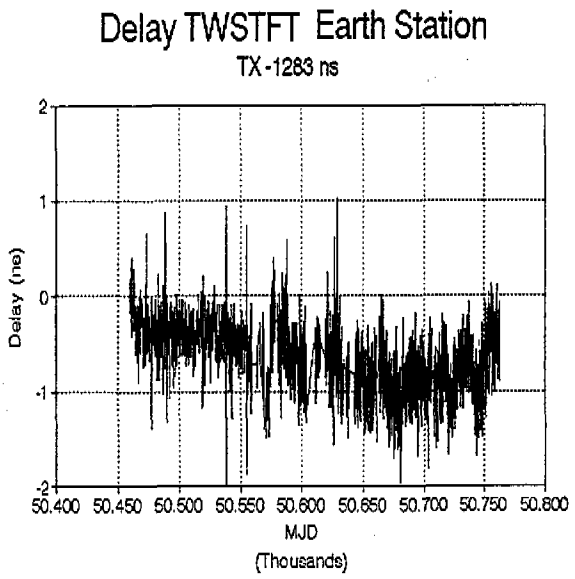

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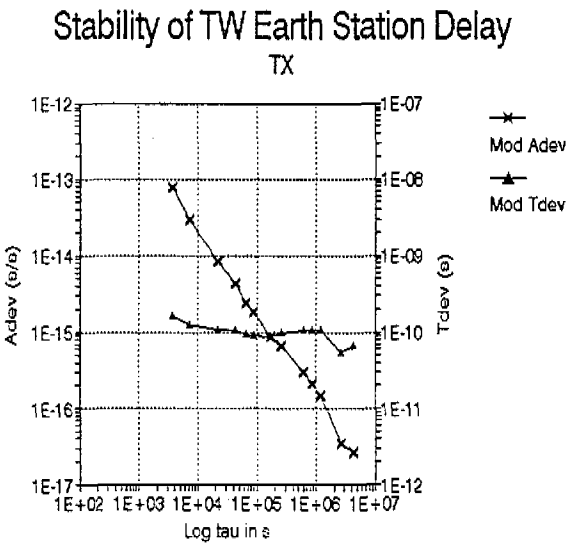

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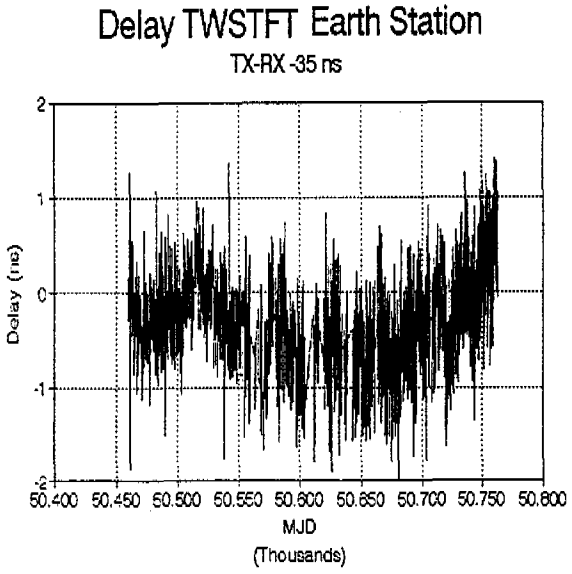

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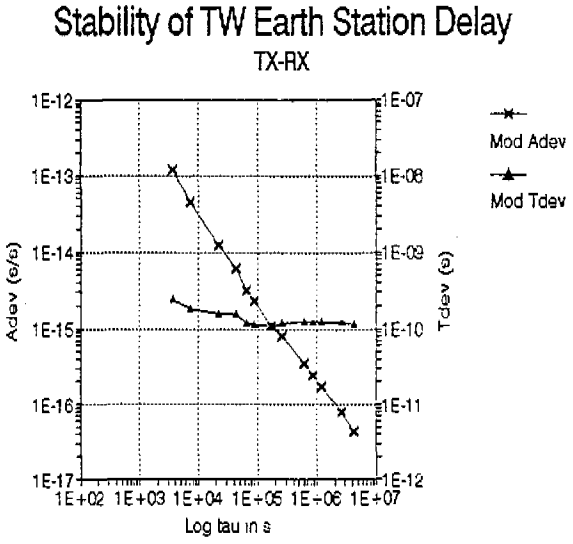

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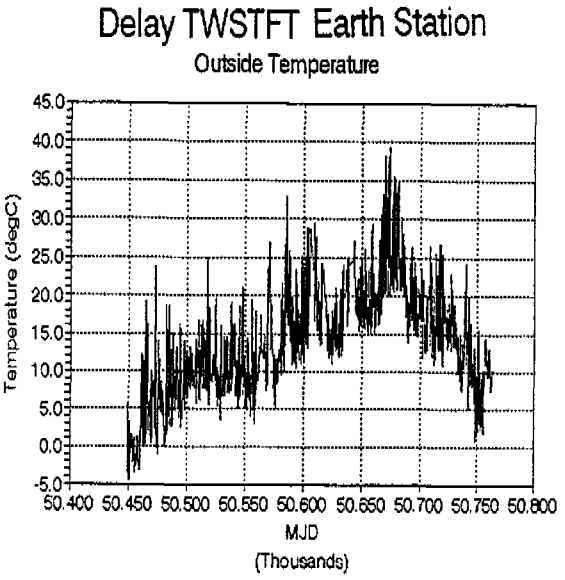

Fig. 12a

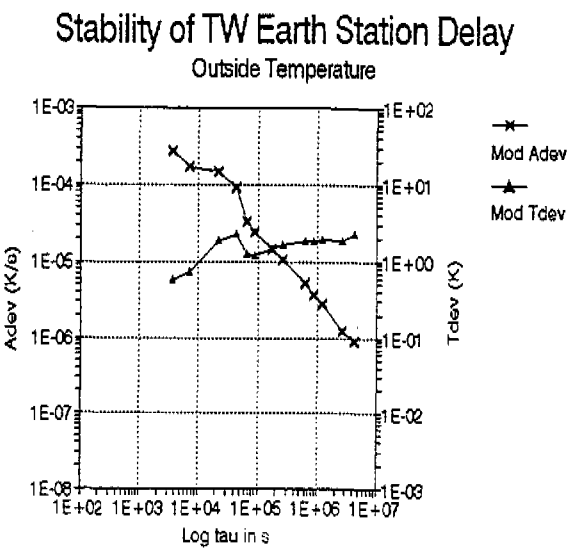

Fig. 12b